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A REPORT ON SOME ALLOCTHONOUS PEAT DEPOSITS OF FLORIDA¹

PART II: MORPHOLOGICAL

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(WITH PLATES X AND XI)

Previous to the eighteenth century the question concerning the origin of coal was not debatable, since it was taken for granted that it had arisen as a result of special creation, or during the Noachian deluge by sedimentation (14). About 100 years ago, however, the increasing value of coal in the industrial world led many investigators to seek a scientific solution for the problem. One of them, VON BEROLDINGEN, came to the conclusion in 1778 that coal was transformed peat similar to that now found in swamps. After this first step in the right direction, many other students formulated theories as to how the process had taken place. Out of the resulting heterogeneous mass of contentions only two tenets have survived, namely, the allocthonous and autocthonous modes of peat and coal formation. All modern students of the problem are agreed that ancient beds have been produced by an accumulation of organic detritus derived from the old lycopod flora, but there are important differences of opinion still as to the method by which this has been accomplished.

Since detailed and elaborate presentations of the drift and *in situ* hypotheses have found a place in many publications upon the subject, more than a brief review of them would be superfluous in this connection (8, 9, 10, 11, 14, 15). Those favoring the first doctrine maintain that these accumulations of much comminuted plant débris, commingled with the more resistant elements, such as spores from vascular cryptogams, carbonized wood (the "mother of coal"), cutinized parts of plants, etc., were deposited very slowly in the bottoms of permanent and open bodies of water, similar to

¹ Contribution from the Laboratories of Plant Morphology of Harvard University.

the method characteristic of lacustrine peat beds. Those opposing this doctrine, the autocthonists, reject the idea that this represents a sedimentation of plant derivatives in open water, but contend that it consists of a gradual amassing of successive generations of lowland plants by prostration *in situ*. The strata, thus exposed, were preserved from decay by a permanent though concealed water supply, as is true and characteristic of the upper stratum of peat deposits in our swamps.

The solution of this vexatious problem, as to which of the two processes is the more probable, has been attempted for the most part by geologists, and naturally enough they have sought explanation topographically. To be sure, the results obtained by numerous investigators in this direction have furnished many valuable data relative to the formation of coal beds, although many of the proofs upon which their conclusions are based are open to serious objection. For example, the presence of stigmaroid roots in coal beds and the supporting shales has been hailed frequently as valuable testimony for an autocthonous origin of the strata in which such structures are found. A broader survey of the problem shows that these rootlike organs are by no means conclusive ground for this deduction, since they also occur quite commonly in cannel coal (a type universally agreed to have been formed in open water), and consequently, a statement which argues equally for either process is unreliable. In this same connection it might be well to mention the quality of the so-called "fire clays" usually found below coal beds. Those who believe that the majority of our coal seams were laid down *in situ* see in the material conclusive proof that this inorganic layer was at one time the subsoil of swamps, owing to an absence of certain minerals which, in their opinion, could have disappeared in no other way than through extraction by growing plants. They fail, moreover, not only to show that this chemical state could not have been brought about by prolonged leaching, but also to account for similar strata in regions which reveal no evidence that they at one time supported forests. In like manner, other topographical features might be shown to present similar objections in favor of sedimentation or an accumulation in place, but this will suffice to illustrate that megascopic investigation alone

is inadequate for reaching substantial conclusions, and therefore it becomes necessary to seek some other means of attack, such as the microscopical study of the material itself. It is evident that the anatomy of coal and peat must be determined before the process whereby they have been formed can be demonstrated clearly.

Studies of the formation of peat, and consequently coal, may be divided into 3 main classes: (1) topographical,² (2) ecological, and (3) anatomical.

Topographical features have been considered sufficiently to show that they, especially in relation to coal, are not entirely reliable as a final factor in determining the origin of all classes of organic deposits. The ecology of peat forming plants likewise is limited in its application, and accordingly will receive only a brief consideration, for two reasons. In the first place, literature is quite complete in its descriptions of the usual zones of growth in swamps, including careful enumerations of all species of plants characteristic of them (2, 6, 10, 11). In the second place, these plants as such enter but little into the formation of the major part of our peat deposits. Even in swamps only a very small proportion (4-6 per cent) has been derived directly from this flora growing *in situ*. As will be shown later, by far the greater portion of our peat deposits represents a sedimentation of macerated plant material in open bodies of water, and as such is not dependent upon any one zone of growth, but rather upon all indiscriminately. For this reason, the two first named branches of the discussion will not be considered further, except for an occasional reference in connection with the microscopical studies of several characteristic peat beds.

Before discussing any special bog, however, it may be well to introduce a brief description of allocthonous and autocthonous peats as they appear under the microscope. It is possible, of course, to discern with reasonable certainty the methods by which any of our present peat deposits have been accumulated, since one has but to choose his material from clearly defined areas; that is, samples selected from modern lakes present detritus which

² FORSAITH, C. C., A report on some allocthonous peat deposits of Florida. Part I: Topographical. BOT. GAZ. 62:32-52. 1916.

has been deposited in open water, while the very upper stratum of swamps is as equally typical of a cumulative origin in place. A microscopical examination of preparations from open lake deposits shows much minute material, both organic and inorganic. The inorganic constituent may be quite variable, depending upon the character of the surrounding country. If the shores and bottom of the pond are of a sandy nature, and the environment much broken by hills or mountains, a condition favorable for rapidly flowing streams, much sand may be found. On the other hand, if the land is quite level and densely forested, the buoyancy of inflowing streams is much reduced, and the inwash from the shores does not carry any large amount of inorganic material on account of a turflike protection. Consequently, the peat found in such regions will be more or less free from earthy inclusions. This difference in the mineral content of peat in rugged and level tracts is significant, and may throw light upon the topography of coal beds during the period of deposition. All available evidence indicates that the external characters of coal beds were very similar to those just mentioned, inasmuch as the land was flat and heavily forested.

Other inclusions found in peat are the calcareous remains of *Chara*, limy silts, diatomaceous tests, and the shells of mollusks. In addition to these mineral substances, which are small in amount, there occurs the more strictly organic material, derived from more or less macerated portions of plants and minute organisms of sedimentary origin. Some of the most conspicuous of these elements, as well as the most important from the scientific standpoint, are pollen grains of the Abietineae and catkin-bearing angiosperms, and spores from ferns, fungi, etc., representing bodies quite analogous to the microspores and megaspores so habitually found in coal. It is especially important to note that normally autochthonous peats do not show the characteristic spore content so universally found in open water formations. In addition to this microspore material, one finds upon an examination of lacustrine samples a rather large volume of amorphous material. Imbedded in the flocculent matter, there appear ingredients the form of which is more intact, such as woody and herbaceous plant fragments, idioblasts from water lily stems, strips of cutinized epidermis, etc.

Besides these plant remains there are certain animal derivatives characteristic of allocthonous peat; for example, ejecta from fish and small aquatic animals, often containing pollen, diatoms, and bacteria; chitinized portions of insects; spicules from fresh water sponges; infusorial bodies; and shells of mollusks and protozoans.

In contrast to the usual inclusions in allocthonous peat (pollen, diatoms, spicules, idioblasts, etc.) there is the strictly autocthonous peat composed of more or less disorganized plant débris. A superficial examination of this material shows a light brown fibrous or dark brown granular texture, depending upon whether or not the included plants are herbaceous or woody. If the substance is more completely decayed, owing to prolonged maceration and the action of fungal enzymes (unhindered by a constant water covering as is true of allocthonous layers), the fallen plants may become so structureless that they resemble humus rather than peat. Under the microscope this form appears quite homogeneous in contrast to the more fibrous and less decayed *in situ* peats, but seldom do the distinguishing features of lacustrine peat appear, only a tangled mass of roots, stems, and leaves in all stages of decay.

Thus it is apparent that there are two distinct types of peat, presenting structures each peculiar to itself, dependent upon the mode of deposition. If a specimen of coal, therefore, can be shown to present a structure analogous to either of these two more recent formations, it is but natural to assume that its composition is due to similar processes of deposition. Strangely enough, this has not been the usual mode of reasoning. Although it is authoritatively asserted that by far the greater number of the peat deposits in the United States are allocthonous in origin, a diametrically opposite view is maintained in respect to the genesis of coal beds. Consequently it will be the object of this paper to show (1) that these two types of peat are microscopically distinct; (2) that some of the bogs (especially swamps) are not, as is usually believed, of *in situ* derivation, but filled lakes in which the peat mainly represents the lacustrine or open water phase; and (3) that coals in general show clearly the organization of allocthonous peat.

The methods used in carrying out these investigations were as follows: Samples of different types of peat were carefully chosen

from localities throughout a wide range extending from eastern Canada to Florida. The numerous deposits were so selected that all stages in the formation of peat beds were inspected, including large and small deep lakes with sandy shores; filled lakes where the zones of growth have entirely covered the former body of water with a layer of accumulated vegetation; large and small shallow lakes; and swamps and river estuaries. At every station a vertical series of samples was secured at 1 ft. intervals. The probings were made over a sufficient area to allow an estimation of the depth and extent of each deposit. The specimens were obtained by the use of a probe devised by DAVIS (3), and stored in cloth sacks. A careful record was made concerning the topography of the region, the gross character of the material, and the depth from which it was taken. These specimens were later studied microscopically in order to determine the correlation between the grosser structures and the minute anatomy in respect to the mode of deposition.

Turning to the more detailed consideration of the several progressive steps in bog formation, Lake Weir in Florida may be considered as an example of the first stage. Sandy shores surround this body of water, and probings show that there are no accumulations of organic detritus nearer than 100 yards off shore; while beyond this there appears a quite extensive stratum of lacustrine peat. A gross examination of the material showed a consistent homogeneous mass, the grayish color of which is due to a calcareous silt. In addition, there appears a very large amount of diatomaceous and limy remains of extinct plants and water animals. The more peatlike content manifests itself as pollen of abietineous and amentiferous derivation, amorphous matter, root fragments (the stigmarioid rootlets so characteristic of certain samples of coal), and herbaceous and ligneous elements from the higher plants.

Attention may now be directed to the more organic peats in order to establish their relation to coal more definitely. In the first place, I shall consider two forms, the one modern and the other ancient, the origin of which is undoubted, namely, lake peat and cannel coal. Samples of lacustrine "muck" were found in the centers of Lakes Newman, Orange, Griffin, Harris, Apopka, Eustis, and many others in Florida, New Hampshire, Massa-

chusetts, and eastern Canada. In general, the samples obtained by probings were deep brown and plastic. They were fine and uniform in texture, without large or fibrous inclusions. As the topographical features around Lake Harris, in Florida, dispel any doubt as to the allocthonous genesis of the stratum there found, preparations from it will be discussed in detail. Fig. 1 represents a sample taken from near the top, and a careful study of it shows clearly pollen grains imbedded in an amorphous mass of drifted and windblown floatsam, ejecta from water animals, etc. A small spore may also be observed. Sponge spicules and idioblasts from water lily stems likewise appear.

A deposit very similar to the one just described was found in Lake Dot, a small dumb-bell shaped body of water near Eustis. This lake is very interesting as an example of those deep bowl-like depressions, known as "lime sinks" (12), which are caused by a subterranean solution of the underlying limestone, so that the roof, becoming too thin to support its own weight, falls. Fig. 2 illustrates a section 3 feet from the top of a 9 ft. layer, and the characters pictured were found by a study of the entire series to be uniform throughout. It will be seen that this sample presents the usual structureless material, ejecta, idioblasts, and pollen. In fact, such structures as are usually encountered in lake "mud," but absent from autocthonous deposits.

The central layers of the peat in Lake Eustis furnished the material shown in fig. 3, which shows several diatoms of the *Staurosira* and *Navicula* type, in addition to spicules from decayed fresh water sponges. The section also shows 3 specimens of the amoeboid *Arcella*. Other features already found to be characteristic of lake precipitations are idioblasts, pollen, etc. Fig. 4 represents a sample of peat much like those just considered, except that there are more plant fragments. The section from which this sample was taken depicts the type of peat found in Lake Orange a mile off shore, and the topography of the region, as well as the microscopical structure of the material, shows it to be of undoubted lacustrine origin. Although many other deposits throughout a wide range were studied, these 4 illustrations are sufficiently characteristic of all deep water formations, as well as the lower layers of bogs, to

demonstrate the distinctive features of all such lacustrine accumulations.

It is at least significant that cannel coal, which is universally considered to be of open water derivation, should manifest the same structures so generally found in lake peat. Both of these fuels, when microscopically examined, present a considerable spore content. In fact some of the cannels (especially tasmanite) as well as their modern homologues were found by JEFFREY (7) as a result of studies of a great number of carefully prepared sections to be almost entirely sporiferous. A somewhat clearer idea of this correlation may be obtained by a reference to fig. 5, which exhibits the organization of Kentucky cannel coal as it appears under the microscope. Scattered throughout the section there may be seen numerous light bodies, which are the flattened spores of vascular cryptogams (homologues of the spores and pollen shown in the illustrations of allocthonous peat). The long grayish bands are indicative of metamorphosed bits of wood. Separating these spores and lignitoid fragments are dense black masses of amorphous organic material. In comparing this illustration with fig. 4, it is apparent that both the recent and prehistoric deposits show a striking anatomical similarity. Thus it would appear that whenever a peat and coal show like organization it has been brought about by the same methods of deposition. It will consequently be assumed in the sequel that similarity of structure, as between peat and coal, implies an identical mode of origin.

Since the next stage in peat formation is illustrated by those areas where the zones of growth are starting to form around the shores, an example will be given. The shores around Lake Orange in Florida show this fringe of water plants quite well. The peat derived from this vegetation consists of fragments of amphibious angiosperms, among which rushes, water lilies, pondweeds, etc., are common. Although the plants which are found in this zone vary systematically in wide ranges, the peat formed by them is uniform. Since the parts of plants which enter into the composition of this peat are very minute, specific differences are not of importance, and consequently any enumeration of them is omitted. Although it is allocthonous, samples taken from this deposit are of

a light brown spongy nature. Fig. 6 presents a preparation from this material, and it will be seen that there are many parts of plants in a perfect state of preservation due to a perpetual covering by water. Other structures more definitely related to lake peats are idioblasts and parts of insects.

Florida is especially favorable for studies of this type of peat, owing to an abundance of "saw grass" (*Cladium*) marshes about Lakes Harris, Griffin, Apopka, and in fact generally throughout the Everglades. If one were to rely solely upon a superficial examination of this material, representative of the later stage in herbaceous marsh development, he would reach the conclusion that these deposits have been formed by a growth of herbaceous plants *in situ*. A detailed examination of samples from different depths, however, shows that this is not a correct interpretation. On the contrary, these paludal accumulations, with the exception of the uppermost layers, are obviously allocthonous. A sample secured 3 ft. from the bottom of the marsh bordering Lake Harris is pictured in fig. 7. This illustrates conclusively that the material has not been formed *in situ* by a gradual amassing of fallen plants, but rather by a floating together of drifted and wind-blown matter similar to that characteristic of deeper lake deposits, as indicated in figs. 1-4. The usual structures found in lacustrine peat, shown in fig. 7, are pollen grains, idioblasts, plant fragments, ejecta, and formless drift. Although no sponge spicules and diatoms appear in the illustration, it should be added that they are of common occurrence. This kind of peat is usually encountered in the lower four-fifths of "saw grass" marshes, as determined by vertical series of samples. The upper layer, nevertheless, has been accumulated in a different manner, since the microscope reveals only the tangled remains of fallen herbaceous plants, and the structures usually found in open water deposits are conspicuously absent. It is probable that this distinct change in the process of deposition was accomplished at some time when the material had so collected that the mass was above water, for a part of the year at least, so that plants perishing in place were allowed to become more or less reduced owing to exposure, and not permitted to float away and become precipitated among the usual sedimentary detritus. It is

apparent that this peat, a very common type in the Florida lake region, is not, as is ordinarily supposed, of autocthonous derivation; but, on the contrary, is almost entirely allocthonous. It would thus appear that the development of this form of deposit is in accord with the general principle of sedimentation for peat and coal in general.

One of the most interesting phenomena in relation to the formation of peat beds is that illustrated by completely or nearly filled lakes. As has previously been stated, there are several distinct steps in the process, beginning with an open lake surrounded by sandy shores, of which condition Lake Weir served as an example. The next is seen where the herbaceous zone has crept in from the shores, as illustrated by the "saw grass" marshes around Lake Harris. The third stage is the conversion into a bog as a result of drainage and the introduction of woody plants, which marks the end of the process. Consequently, the value of this last formation as a peat builder has in all probability been overestimated, since the detritus formed by it directly comprises but a small proportion of the whole, especially in the more tropical areas where perpetual exposure is favorable to destructive activities. A series of samples from one of these beds, if studied only superficially, shows two distinct types of material: the upper layer consisting of a tangled mat of fallen plants and roots, and the lower layer consisting of a somewhat homogeneous mass of minute débris. This older plastic material is believed by many writers to have resulted from a more prolonged period of reduction of detritus similar to that found in the upper part of the bed. This conclusion, derived from gross examinations alone, is nevertheless misleading, and on this account it seems advisable to refer to microscopic investigations. A bog near Leesburg will serve to illustrate. A topographical study of this area showed that it was at one time either an arm of Lake Harris or a connecting link between Lake Harris and Lake Griffin. At the present time the filling processes have reached completion, and the entire area is now dry land bearing a dense forest of coniferous and deciduous trees. Probings in several localities showed about 15 ft. of peat resting upon a stratum of bluish clay (the initial stage of "fire clays" usually found under coal beds). Above this lamina

there occurs a layer of fine black peat, similar in form to that now found in the open lakes. This is the "completely decomposed stratum" just mentioned. Fig. 8 shows a microscopical section taken 3 ft. from the bottom, and further studies of the figure reveal in addition to the usual structureless drift, woody and herbaceous plant fragments, pollen, spores, spicules, etc., all of which have been preserved from decay by a perpetual water cover and natural acidity. It is manifest that this material does not represent the final stage in the reduction of fibrous peat, but rather an accumulation of drifted and wind-blown matter which was precipitated at some time when lacustrine conditions prevailed. This relation is still more obvious when it is demonstrated to be similar in the most exacting detail to that already shown to be characteristic of present lake deposits and illustrated in figs. 1-4. Above this dark amorphous mass, there appears a light brown fibrous material like that already described for the "saw grass" marshes. Fig. 9 shows photomicrographically the true nature of the substance. In addition to root fragments across the illustration, there appears the usual disorganized material, pollen, spores, and spicules, all of which indicate an allocthonous origin. An even clearer idea of the lacustrine nature of this peat may be obtained by reference to fig. 10. In the upper right hand corner of the figure is a much distorted fragment from some herbaceous plant, amorphous matter, and ejecta. The most noticeable, as well as one of the most significant, features, however, is a fern sporangium and a sponge spicule which could not occur in juxtaposition except through sedimentation in open water.

Microscopical studies of this vertical series indicate that about the time when the last of the herbaceous material had been deposited, the accumulated mass was above water level, thus furnishing a somewhat drained soil for the growth of more woody plants. Consequently the amphibious species were forced to move on, and their place was taken by woody trees and shrubs. This later growth in turn built up a layer of autocthonous peat which shows the remains of comminuted material, but none of the structures so characteristic of the allocthonous layers below. In securing these samples some difficulty was experienced in forcing the probing

instrument through the tangled cypress logs and roots, which resisted decay more than the dicotyledonous trunks and settled through the ooze-like mass below. Although these structures are not general in peat beds, they are by no means uncommon, and in all probability have homologues in coal beds, a fact which has led to the idea that they are indicative of an autocthonous origin for coal. Like all other megascopic evidence, however, the interpretation of these structures is open to question, since conditions like those in the bog just mentioned might have prevailed in the past, and fallen logs settled through the unresisting lake peats below the growing stratum.

It must be apparent that allocthonous peats in this region are vastly predominant over those laid down in place, which is quite in accord with the statement of DAVIS (15), namely, "the fact [is] that at the present time peat deposits of this type [lacustrine] are numerically more important than any other in regions where peat formation is common." The even more pronounced dearth of accumulated generations of plants *in situ* in this region than is usual in the more northern bogs is without doubt due to climatic conditions, which in warmer localities are more favorable to the destructive action of fungi. Since Florida now has a climate similar to that generally ascribed to the coal-forming periods, it seems logical to infer that strictly *in situ* depositions were equally scarce during ancient times. This phenomenon is well illustrated, in fact, by several swamps in Florida where the sandy floors do not present any quantity of autocthonous peat. For example, in an extensive swamp near Gainesville there appears a dense growth of cypress, pine, and dicotyledonous trees growing up through an almost impenetrable tangle of fallen trunks in all stages of decay. One can hardly imagine a more favorable location for the accumulation of autocthonous peat, but in spite of this, an examination showed but a few inches of humus-like substance derived from comminuted plants.

Although these Florida peats present conditions of environment more like those which formerly prevailed over the entire earth, some attention should be paid to the more northern deposits, as in all discussions of the problem of coal formation, they are mentioned

as the counterpart of "autochthonous" coals. A bog of this type near Fresh Pond in Cambridge, Massachusetts, will serve as an example. Samples were taken in the usual way throughout the entire 30 ft. of the deposit. With the exception of the extreme upper stratum, the samples present a uniformly brown plastic consistency, similar to that found in open lakes. A subsequent examination revealed that the lower 28 ft. were singularly constant in respect to structure, and composed of the usual amorphous material in which were imbedded pine, larch, and amentiferous pollen; spores and sporangia of ferns and fungi; vast quantities of diatomaceous tests and sponge spicules; minute fragments of roots, stems, and leaves of the higher plants; and animal derivatives such as insect parts, water organisms, and ejecta from aquatic creatures. All of these structures are very similar to those shown in figs. 1-4, with the exception of unimportant northern and southern floral differences. There also appeared in this layer some indications of carbonized woody fragments which had been washed into this former lake from a region swept by a prehistoric forest fire, and there deposited. This fact is significant, since such structures are of common occurrence in coal sections in juxtaposition with unburned material, precluding the possibility of deposition *in situ* (7). These inclusions, together with the wonderfully perfect preservation of the débris even in the very lowest strata, dispel any doubt that it is of an allochthonous origin, and not one brought about by an accumulation of fallen plants which later decay to a structureless mass (the "completely decomposed peat" of many writers).

The next swamp to be considered is a so-called "*Sphagnum* bog" in Auburn, New Hampshire. This deposit is found in depressions between long irregular ridges, in the form of the letter Y, about 2 miles in length and half a mile in breadth. In the central portion there occurs a chain of more or less circular ponds surrounded by the usual zones of growth, the inner zone of which is distinctly sphagnoid. A series of tests showed a layer of lacustrine peat about 27 ft. in depth. Above this and near the ponds there is a floating "mat" of *Sphagnum* and other plants about 1 ft. in thickness. Back from the shores there appears a tangled mass of roots and fallen plants above this mossy stratum. Excepting

this thin autocthonous deposit, all the microscopical sections showed "muck" formed by sedimentation similar in composition to that already described for the bog in Cambridge and in more southern regions. Material from several lakes in eastern Canada was minutely examined, and structural evidences of allocthonous peat were found to correspond so closely to those in the United States that any further discussion of them is unnecessary.

Since the shallow or intermittent lakes are not favorable to an accumulation of any appreciable amount of peat, owing to periods of drought and constant agitation by waves, they will receive but brief consideration. Many of this type were observed around Zellwood and Lake Tohopekaliga in Florida, and several small ponds in New Hampshire. In all there was little peat, especially in the south, where there are distinct wet and dry seasons favoring the destruction of whatever material may have gathered during periods of inundation.

There now remains only one distinct kind of fresh water peat to be considered, namely, that found in river estuaries. One example at Pablo Creek near Jacksonville, Florida, will be discussed. Topography indicates that the space between two elevations was once occupied by a river a mile in breadth. This broad stream gradually filled its bed with organic material until the mass had sufficiently accumulated so that the entire depression was covered by an allocthonous layer of peat, excepting the channel of a meandering river. Tests showed a uniform deposit about 12 ft. in depth. Fig. 11 shows the microscopical character of the material, and studies of the entire vertical series indicate a general uniformity. It will be observed that coniferous woody fragments are very abundant, as indicated by a uniseriate ray in tangential section and an absence of vessels. There are also present the more evident lacustrine derivatives, such as a broken sponge spicule, pollen, amorphous material, and a group of spores. These structures indicate that the deposit, like those found in the now open and filled lakes, has arisen by similar processes of deposition in open water.

The peat illustrated in fig. 11 is especially favorable for comparison with thin sections of the more lignitoid coals (bituminous)

as shown in fig. 12. This pictures a microscopical section of bituminous coal from Perry County, Ohio. Crinkled bands of compressed wood are especially distinct in the upper and left hand parts of the figure, and evidences of an allocthonous origin for this coal are present as flattened spores, appearing as light bodies imbedded in a dense black amorphous matrix. Both the lignitic coal and the woody peat show a large and varied amount of xyloid material in addition to the more obviously lacustrine derivatives, such as spores, etc., which have been shown to be characteristically absent in "swamp" peats. It seems logical to conclude, therefore, that these substances so alike in structure must have arisen by a similar process, and for this reason any coal showing a high spore content should be considered as having been formed in the same manner which obtains in present deposits; that is, in open water, and not by an accumulation of fallen plants *in situ*, as stated by the older geological publications upon this subject (1, 5, 11, 14, 15).

Since it is generally admitted that natural factors, such as climate and topography, have been instrumental in the formation of our coal beds, it is obvious that a correlation between past and present phenomena is essential for a precise understanding of ancient and modern peat deposits. In regard to climate, competent investigators are quite agreed that there was a somewhat warm and humid atmosphere over the earth during the Carboniferous and later peat-forming epochs. This supposition is corroborated by observations of fossil remains characteristic of the different periods which show a usual lack of annual rings. The nearest parallel to these climatic conditions of growth is now found to prevail only in semitropical and tropical regions. Because of the importance of these considerations, the writer has chosen many of his illustrations from the semitropical peat deposits of Florida, since they present a closer analogy to coal beds than do the more northern organic strata. It has already been pointed out that there is a surprising lack of autocthonous accumulations in this locality in contrast to an abundance of lacustrine deposits. This dearth of land-formed peat is clearly dependent upon the rapid decay of exposed land plants in zones without a winter season. Accelerated disintegration under these conditions is sufficiently pronounced to

prevent any appreciable amassing of vegetable matter other than that protected by a continuous covering of water. Studies of coal sections indicate that similar processes were as effectual in the past, for there is a universal deficiency of strictly autocthonous coals as revealed by the microscope (8).

Although this prehistoric lycopod flora, growing on the low-lying shores of ancient lakes, was different from that which now enters into the formation of peat, the process by which fragmentary material was derived from this cryptogamic growth was undoubtedly the same. JEFFREY (8), as a result of his studies of sections of coal from all over the world, has found that all categories from cannel to anthracite show spores of arboreal cryptogams in varying amounts, just as the peats of today show different proportions of pollen. In addition to the many spores carried into these carboniferous lagoons by the wind, sluggish streams brought microscopic débris in all stages of decay. This detritus was precipitated, and the allocthonous peat was augmented by an age-long process of sedimentation. A continuance of such conditions finally raised the mass above water when the bordering forests, in zones like the present, marched toward the center and established swamps. This bog-loving flora did not, however, add in any appreciable degree to the substance already accumulated, owing to their rapid decay in a fallen state, both as a result of a warm climate and its less resistant organization. In fact, all microscopical evidence points to a condition very similar to that already described for recent peat deposits, the major part of which is quite conclusively shown to be of drifted derivation.

Another fact which supports the allocthonous theory of coal formation, is the vast predominance of lacustrine peat over *in situ* deposits at the present time. This fact has been well illustrated by the several strata already mentioned, such as those found in open lakes, filled lakes (swamps), and river estuaries. The phenomena are especially noticeable in warm localities, where autocthonous peats are quantitatively almost negligible.

Thus it is apparent that the mode of peat formation, as illustrated by its anatomical structure and topographical features, shows strikingly similar analogies in coal. It must be assumed, therefore,

that the major part of our coal beds, like peat deposits, does not represent a gradual accumulation of successive generations of fallen plants in swamps, but rather a long continued and peaceful sedimentation of wind-blown and drifted plant fragments and minute organisms in the depths of open bodies of water.

In conclusion, the writer wishes to express his sincere thanks to the Committee of Sheldon Traveling Fellowships of Harvard University for the granting of a fellowship, the stipend of which has made possible these investigations; to Professor R. THAXTER of Harvard University for samples of peat; and to Professor E. C. JEFFREY for advice during the course of the work.

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EXPLANATION OF PLATES X AND XI

PLATE X

FIG. 1.—Composition of allocthonous peat from Lake Harris in Florida; grayish background represents amorphous mass of organic derivation in which there are imbedded abietineous pollen grains, appearing as oblong bodies with 2 laterally attached air sacs; an idioblast from a water lily is pictured in lower left hand corner as a series of spinelike appendages radiating from a common center; other inclusions are dense black ejecta from amphibious animals, and spindle-shaped fresh water sponge spicules.

FIG. 2.—Sample of similar constituents from Lake Dot.

FIG. 3.—Material from Lake Eustis in which there are idioblasts, pollen, spores, spicules, ejecta, and structureless matter; in upper left hand corner there appear 3 specimens of the amoeboid *Arcella*; diatoms of *Stauronesis* and *Navicula* type occur in upper and lower portions of figure respectively.

FIG. 4.—Magnified view of peat from Lake Orange 1 mile off shore; besides characteristic structures, strips of epidermis and an herbaceous plant fragment appear, cells of which are still intact.

FIG. 5.—Organization of Kentucky cannel coal, $\times 250$; scattered throughout the section are numerous light bodies, flattened spores of vascular cryptogams (homologues of the spores and pollen shown in the illustrations of allocthonous peat); the long grayish bands are indicative of metamorphosed bits of wood; separating spores and lignitoid fragments are dense black masses of organic matter.

FIG. 6.—An herbaceous peat from Lake Orange near shore; fragments of roots, etc., manifest cell structure clearly; evidences of drifted material are present, as an idioblast and the mouth part of some insect.

PLATE XI

FIG. 7.—Sample of "saw grass" (*Cladium*) peat 3 ft. from bottom of a marsh bordering Lake Harris; exemplifies the usual inclusions characteristic of allocthonous peat.

FIG. 8.—Preparation of peat 3 ft. from bottom of a bog near Leesburg, Florida, in which are pollen, spores, spicules, ejecta, and other allocthonous inclusions; also woody and herbaceous fragments of plants, cells of which are still intact.

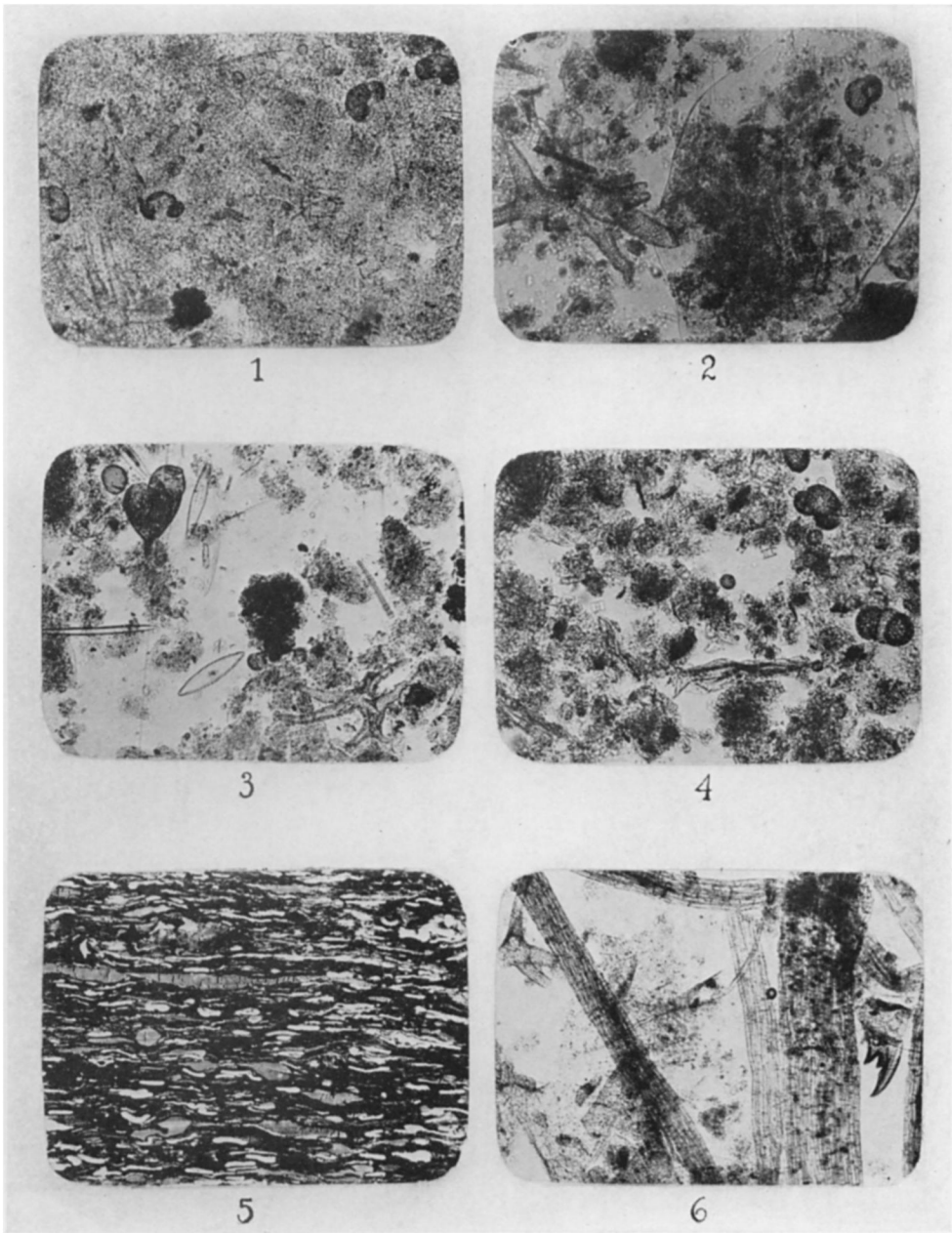
FIG. 9.—Nature of peat above the deep brown plastic layer illustrated in fig. 8; in addition to usual sedimentary matter, intact fragments of herbaceous plants may be seen.

FIG. 10.—Another sample from the same horizontal plane with a much distorted plant fragment in upper right hand corner; below and to left of this, a sponge spicule and fern sporangium may be seen in juxtaposition.

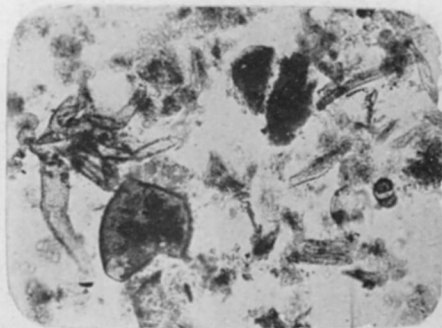
FIG. 11.—A woody peat from Pablo Creek near Jacksonville, Florida, almost entirely composed of lignitoid plant fragments; evidence of a coniferous

origin for this wood is furnished by a uniseriate ray in tangential section and an absence of vessels; indications for a sedimentary origin for this stratum are manifest as a sponge spicule, abietineous pollen, and a group of spores in upper right hand corner.

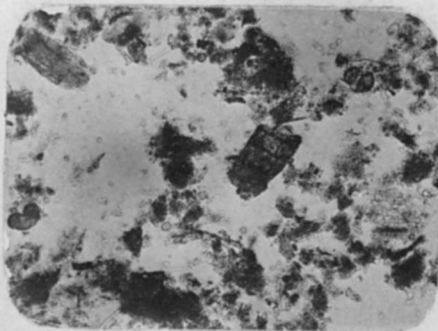
FIG. 12.—A bituminous coal from Perry County, Ohio, $\times 250$; crinkled bands of compressed wood are especially obvious in upper and left hand parts; evidences of an allocthonous origin for this coal occur as flattened spores, appearing as light bodies imbedded in a dense black amorphous matrix.



FORSAITH on PEAT



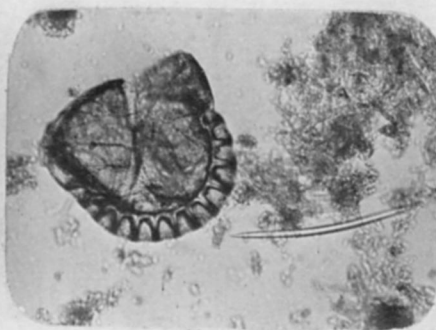
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